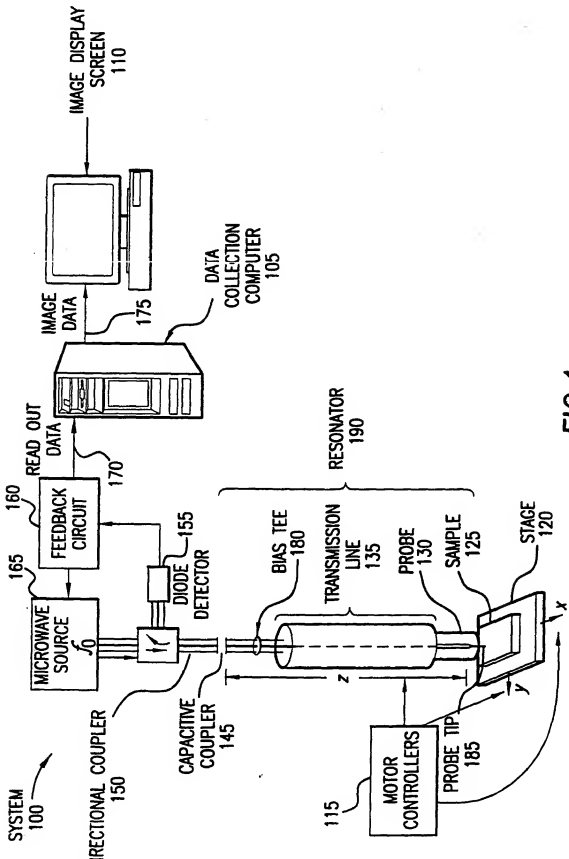
IMAGE DISPLAY SCREEN 110
IMAGE DATA 175
DATA COLLECTION COMPUTER 105
READ OUT DATA 170
160
FEEDBACK CIRCUIT
165
MICROWAVE SOURCE f0
DIODE DETECTOR 155
RESONATOR 190
BIAS TEE 180
TRANSMISSION LINE 135
PROBE 130
SAMPLE 125
STAGE 120
DIRECTIONAL COUPLER 150
CAPACITIVE COUPLER 145
SYSTEM 100
115
MOTOR CONTROLLERS
PROBE TIP 185
z
y
x

FIG. 1

200
SAMPLE 125
PROBE TIP 185
SAMPLE HOLDER (CANTILEVER) 210
SPRINGS 220
230
FIXED TO x-y STAGE
240

FIG.2

300
QUANTITATIVE MODELER
320
PROBE CALIBRATION CURVE GENERATOR
330
TEST SAMPLE CALIBRATION CURVE GENERATOR
310
MODEL CALIBRATION CURVE GENERATOR
105
COMPUTER MEMORY
ELECTRIC FIELD CONFIGURATION DATA
ΔF, Q,

FIG.3

FIG.4

PERTURBATION FORMULA

$$\frac{\Delta f}{f} \approx \frac{\left(\epsilon_{r1}-\epsilon_{r2}\right)}{4W} \int_{V_S} \vec{E}_1 \cdot \vec{E}_2 \, dV$$

$$\Delta f = f\left(\epsilon_{r1}, \epsilon_{r2}\right)$$

FIG.5

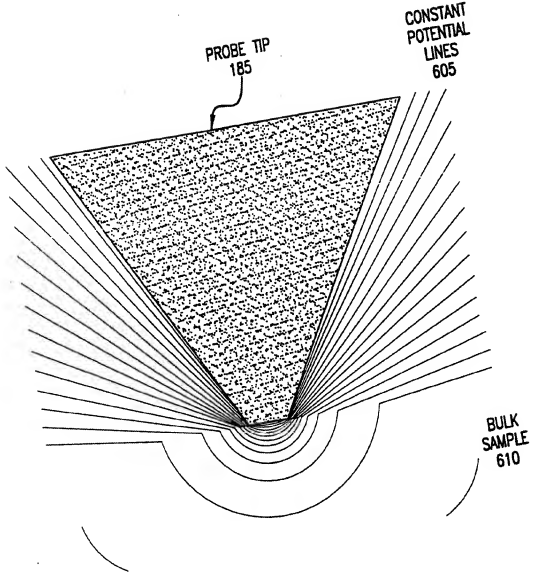

FIG.6

CONSTANT POTENTIAL LINES 705
THIN FILM 710
SUBSTRATE 715
FINITE ELEMENT MODEL
PROBE TIP 185
6 μm

FIG.7

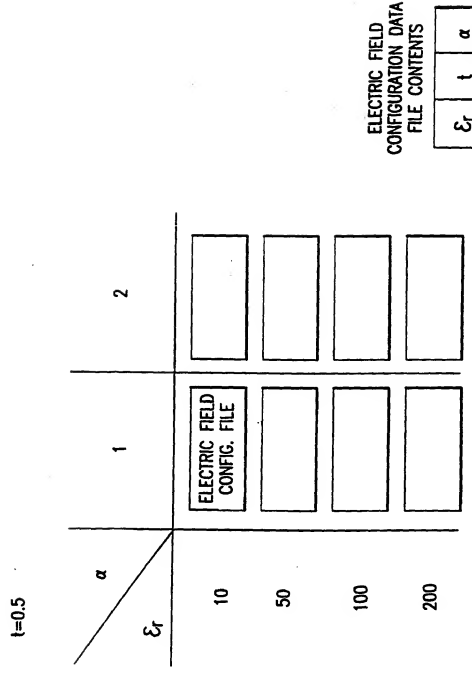
t=0.5
α
ε_r
1
2
10
50
100
200
ELECTRIC FIELD CONFIG. FILE
ELECTRIC FIELD CONFIGURATION DATA FILE CONTENTS
ε_r
t
α
φ(r,z)

FIG.8

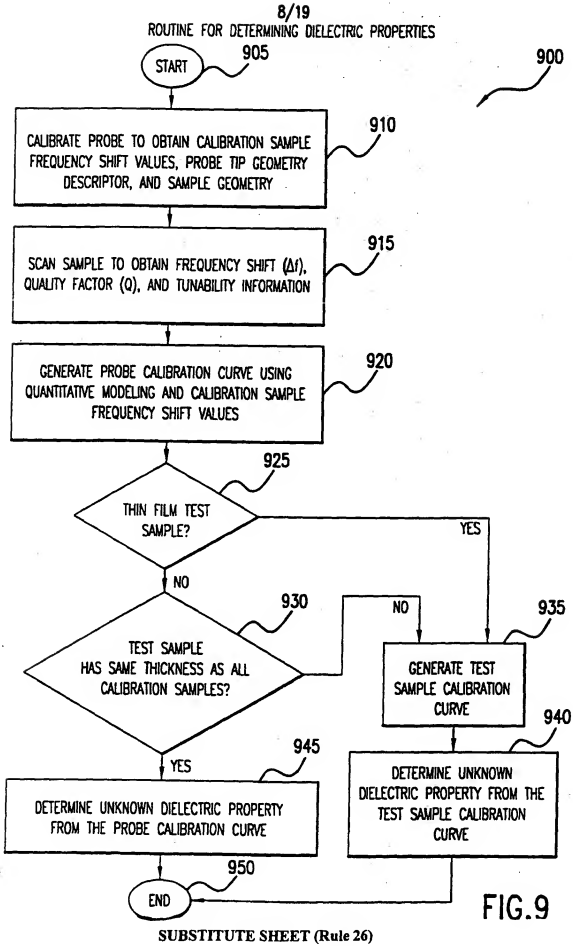

FIG.9

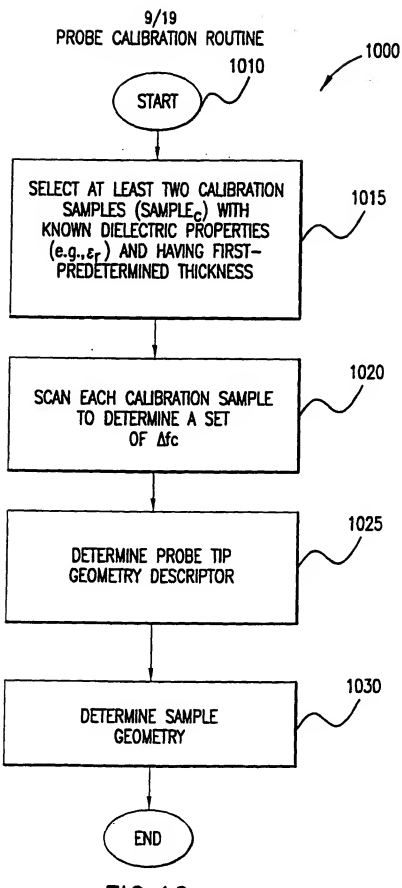
9/19
PROBE CALIBRATION ROUTINE
1000
1010
START
SELECT AT LEAST TWO CALIBRATION SAMPLES (SAMPLE$_C$) WITH KNOWN DIELECTRIC PROPERTIES (e.g., ε_r) AND HAVING FIRST-PREDETERMINED THICKNESS
1015
SCAN EACH CALIBRATION SAMPLE TO DETERMINE A SET OF Δfc
1020
DETERMINE PROBE TIP GEOMETRY DESCRIPTOR
1025
DETERMINE SAMPLE GEOMETRY
1030
END

FIG.10

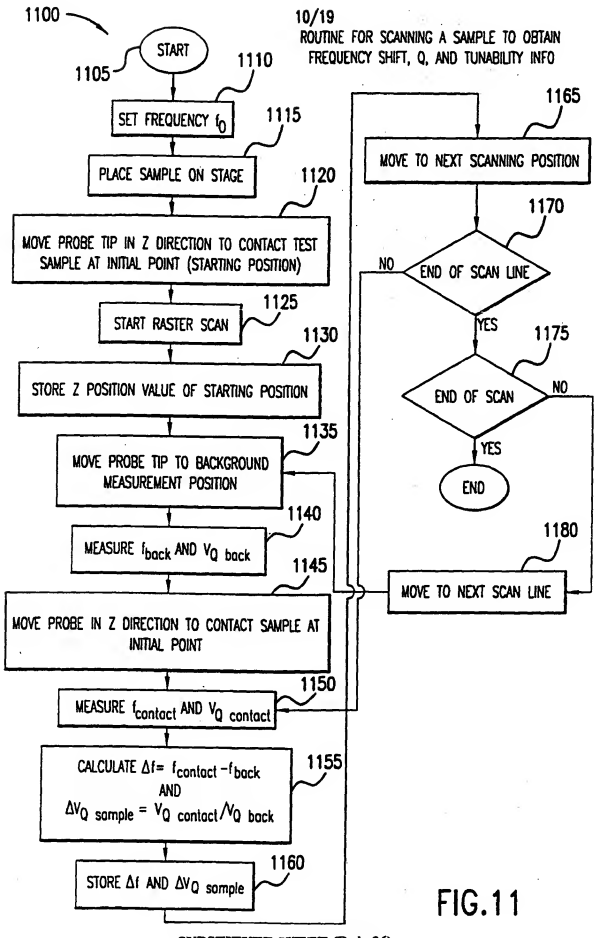
1100
10/19
ROUTINE FOR SCANNING A SAMPLE TO OBTAIN FREQUENCY SHIFT, Q, AND TUNABILITY INFO
START
1105
1110
SET FREQUENCY f_0
1115
PLACE SAMPLE ON STAGE
1120
MOVE PROBE TIP IN Z DIRECTION TO CONTACT TEST SAMPLE AT INITIAL POINT (STARTING POSITION)
1125
START RASTER SCAN
1130
STORE Z POSITION VALUE OF STARTING POSITION
1135
MOVE PROBE TIP TO BACKGROUND MEASUREMENT POSITION
1140
MEASURE f_{back} AND $V_{Q\ back}$
1145
MOVE PROBE IN Z DIRECTION TO CONTACT SAMPLE AT INITIAL POINT
1150
MEASURE $f_{contact}$ AND $V_{Q\ contact}$
1155
CALCULATE $\Delta f = f_{contact} - f_{back}$ AND $\Delta V_{Q\ sample} = V_{Q\ contact} / V_{Q\ back}$
1160
STORE Δf AND $\Delta V_{Q\ sample}$
1165
MOVE TO NEXT SCANNING POSITION
1170
END OF SCAN LINE
NO
YES
1175
END OF SCAN
NO
YES
END
1180
MOVE TO NEXT SCAN LINE

FIG.11

ROUTINE FOR GENERATING A CALIBRATION CURVE

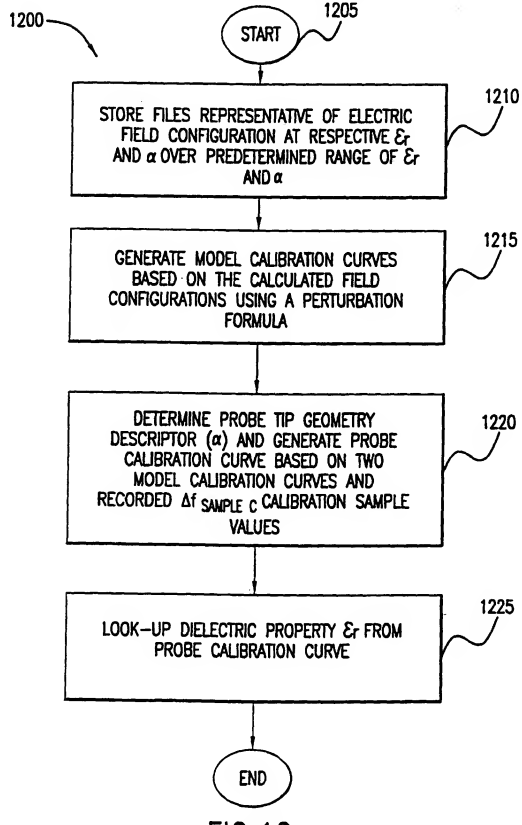

FIG.12

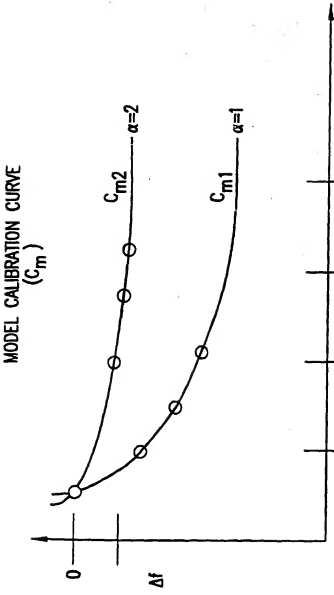
MODEL CALIBRATION CURVE
(C_m)
C_{m2}
α=2
C_{m1}
α=1
0
Δf
10
50
100
200
ε_r

FIG.13

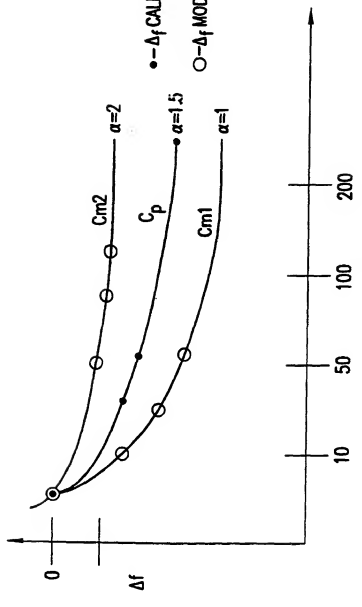
PROBE CALIBRATION CURVE
(C_p)
•—Δ_f CALIBRATION SAMPLE VALUES
O—Δ_f MODEL SAMPLE VALUES
Cm2
C_p
Cm1
α=2
α=1.5
α=1
0
Δf
10
50
100
200
ε_r

FIG.14

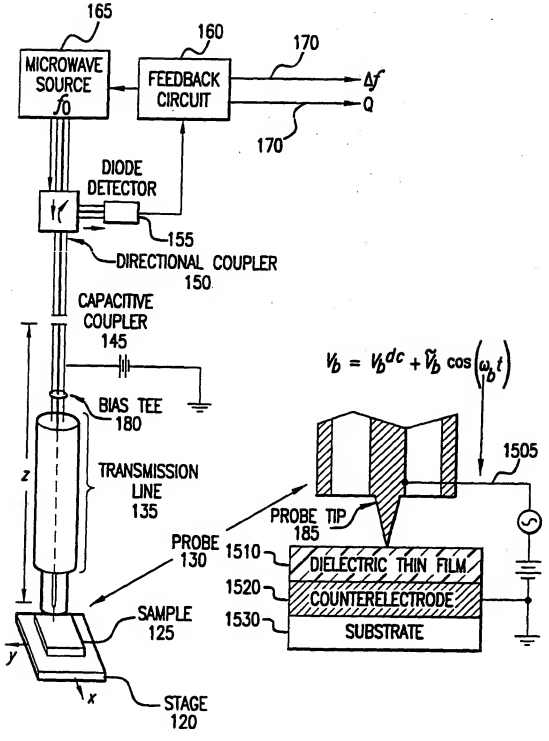
165
MICROWAVE SOURCE
f_0
160
FEEDBACK CIRCUIT
170
Δf
Q
170
DIODE DETECTOR
155
DIRECTIONAL COUPLER
150
CAPACITIVE COUPLER
145
BIAS TEE
180
TRANSMISSION LINE
135
z
PROBE
130
SAMPLE
125
y
x
STAGE
120
$V_b = V_b^{dc} + \tilde{V}_b \cos(\omega_b t)$
1505
PROBE TIP
185
1510
DIELECTRIC THIN FILM
1520
COUNTERELECTRODE
1530
SUBSTRATE

FIG.15

SMALL ASPECT RATIO = BLUNT TIP

$$\text{ASPECT RATIO} = \alpha = \frac{\Delta z}{\Delta r} = \tan\theta$$

HIGH ASPECT RATIO = SHARP TIP

FIG.16

TEST SAMPLE CALIBRATION CURVE
FREQUENCY SHIFT
Δ f
0
10
PERMITTIVITY εr
C_{ts2}
C_{ts}
C_{ts1}
α = 2
α = 1.5
α = 1

FIG.17

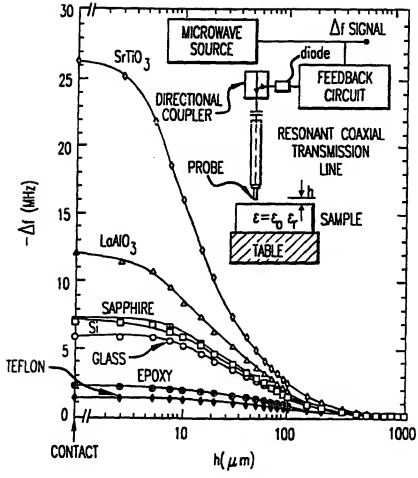
MICROWAVE SOURCE
Δf SIGNAL
diode
FEEDBACK CIRCUIT
DIRECTIONAL COUPLER
RESONANT COAXIAL TRANSMISSION LINE
PROBE
h
ε=ε0 εr
SAMPLE
TABLE
SrTiO3
LaAlO3
SAPPHIRE
Si
GLASS
EPOXY
TEFLON
-Δf (MHz)
30
25
20
15
10
5
0
CONTACT
10
100
1000
h(μm)

FIG.18

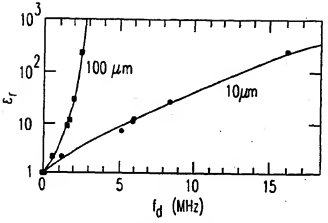

FIG.19

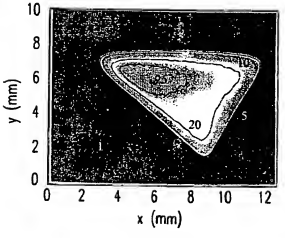

FIG.20

MATERIAL	EXPERIMENTAL VALUE	LITERATURE VALUE	FREQUENCY (GHz)	REFERENCES
SILICON	12	11.7	100	11
GLASS	12	6.7	10^{-3}	12
$SrTiO_3$	180	230	0.1	9
$LaAlO_3$	20	23.9	18	10
SAPPHIRE (CERAMIC)	20	10.0	100	11
TEFLON	2.1	2.1	10	9

FIG.21

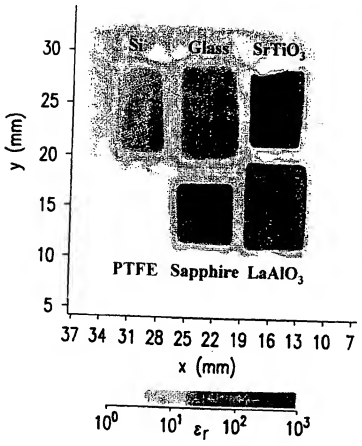

FIG.22A

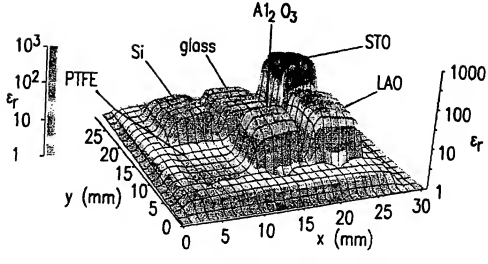

FIG.22B